ТЕХНІКА ТА МЕТОДИ ЕКСПЕРИМЕНТУ
ENGINEERING AND METHODS OF EXPERIMENT

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Mohamed Bencheikh[1,]*, Abdelmajid Maghnouj[1], Jaouad Tajmouati[1], Abdessamad Didi[1], Abdesslam Lamrabet[1], Yassine Benkhouya[2,3]

[1] *LISTA Laboratory, Physics Department, Faculty of Sciences Dhar El-Mahraz, University of Sidi Mohamed Ben Abdellah, Fez, Morocco*
[2] *Department of Radiotherapy, Al Kawtar Clinic, Fez, Morocco*
[3] *University Mohamed V in Rabat, Faculty of Sciences, Laboratory of Nuclear Physics* (*LPNR*), *Rabat, Morocco*

*Corresponding author: bc.mohamed@gmail.com

NEW APPROACH TO EVALUATE THE EXIT DOSE QUALITY FOR HIGH RADIOPROTECTION AND RADIOTHERAPY EFFICIENCY

For safety and radioprotection reasons in radiotherapy treatment, the exit dose is evaluated with irradiation field size and photon beam energy. The objective of this study is to introduce an empirical law for predicting the delivered dose at the other side of patient while radiotherapy treatment of cancer. In this study, the exit dose is the delivered dose out of the phantom on beam central axis. The measurements of percentage depth dose were done as a function of irradiation field size with an uncertainty of 2 % as recommended by IAEA protocols for two photon beam energies 6 and 18 MV. For high radioprotection quality inside radiotherapy department, an empirical law is elaborated with a reliability of 97 %. Thereafter, it consists a basic law that should be used theoretically to know the delivered dose variation with field size at the exit dose point for knowing the behavior of dose outside of radiotherapy treatment region. The medical physicists and physicians should take this law in radiotherapy treatment of the cancer.

Keywords: dose build-up, radiotherapy, photon beam, dosimetry, radiotherapy quality.

1. Introduction

Now, the radiotherapy is an essential technique of the treatment of cancer over the world. Maintaining and improving the quality and safety of radiotherapy involves many activities, which overlap in many levels in the technological development of medical equipment and in the facility in use [1]. The quality of radiotherapy treatment consists to use the radiation in diagnostic and in therapy by as low as possible of risks for patients and staff. The exit dose is undesirable delivered dose that should be managed adequately. The questions should be put in this contest, how this delivered dose varies with irradiation field size for both photon beam energies of 6 and 18 MV?

Technical quality improvement for reducing the exit dose can be seen in a context of the quality management for patients and staff protection. Towards safer radiotherapy, many researches are done previously in many institutes over Great Britain [2]. In the contest to best production of the radiation by Linac, many studies are done to improve its use. For increasing the radiotherapy efficiency, some works are carried out on the isotopes production for brachytherapy [3]. Others however are carried out on the beam filtration system quality for external photon radiotherapy [4, 5] and the removing flattening filter from Linac head configuration to improve its technology [6, 7]. The material and geometry of flattening filter and the quality of photon beam for high radiotherapy efficiency are analyzed in our studies [8 - 10].

The quality assurances (QA) are many conditions which should be verified for using the radiation in treatment and imaging with high efficiency for patients and in safer manner for patients and staff. They are elaborated by many international instances as IAEA, ICRU and AAPM [11]. The goal of QA program for linear accelerators is to assure that the machine does not deviate significantly from their baseline values acquired while the acceptance commissioning [12]. The Linac is used for radiotherapy treatment after completion of some satisfactory scientific methods called as pre-commissioning testing based on many dosimetry investigations for using this machine in the cancer treatment with high radiotherapy quality. The process of commissioning of the Linac for clinical use includes comprehensive measurements of dosimetric parameters that are necessary to validate the treatment planning system (TPS) which is used for selecting the optimal radiation modality and treatment technique for individual patients. Safer radiotherapy is a goal for all international instances and all researchers over the world.

The knowledge of the delivered dose behavior outside water phantom in dependence on irradiation field size and photon beam energy is essential for safer radiotherapy and for high radioprotection quality. The exit dose is a part of the percentage depth dose (PDD), which should be measured for many field sizes and for many photon beam energies for checking out the delivered dose quality and radioprotection. In the present work, the PDDs are measured for two photon beam energies 6 and 18 MV, which are produced by Varian Clinac 2100 with source-to-surface distance of 100 cm.

In this study, we discuss the exit dose as delivered dose at the last point of phantom water in the Z-axis. We have worked on the exit dose with photon beam energy and with irradiation field size by introducing an empirical law to evaluate the exit dose with field size for predicting the delivered dose at the contact point between water phantom and the outside region. This study could be a basic analysis for radioprotection and to reinforce the QA in radiotherapy department.

2. Materials and methods

2.1. Dose measurements

The PDDs are measured using a motorized scanning system (PTW ionization chamber) for many irradiation field sizes. The uncertainty of measurements is less than 2 % as recommended by the Swiss Society of Radiobiology and Medical Physics SSRMP [13]. The source to surface distance (SSD) is fixed at 100 cm for all measurements of PDD.

The uncertainty of PDD measurements includes the uncertainty of experimentation and also the uncertainty of measurement device and it was 2 %. The water is pure water that was put in a tank of volume of 40 × 40 × 30 cm^3.

2.2. PDD function presentation

The PDD is a parameter recommended by IAEA for evaluating the quality of radiation beam for clinical usage [14, 15]. The PDD was determined according to the following formula:

$$\mathrm{PDD}(\mathrm{A};\ \mathrm{d};\ \mathrm{E};\ \mathrm{SSD}) = \frac{\mathrm{D}(\mathrm{A};\ \mathrm{d};\ \mathrm{E};\ \mathrm{SSD})}{\mathrm{D}(\mathrm{A};\ \mathrm{d}_{\max};\ \mathrm{E};\ \mathrm{SSD})} \cdot 100, \quad (1)$$

where D – measured dose; A – irradiation field size; E – photon beam energy; d – depth in water phantom; d_{max} – depth of dose maximum; SSD – source to surface distance.

The PDD curve is presented in Fig. 1 as a function of depth for the photon beam energy of 6 MV, for the irradiation field size of 10 × 10 cm^2 and for the SSD of 100 cm.

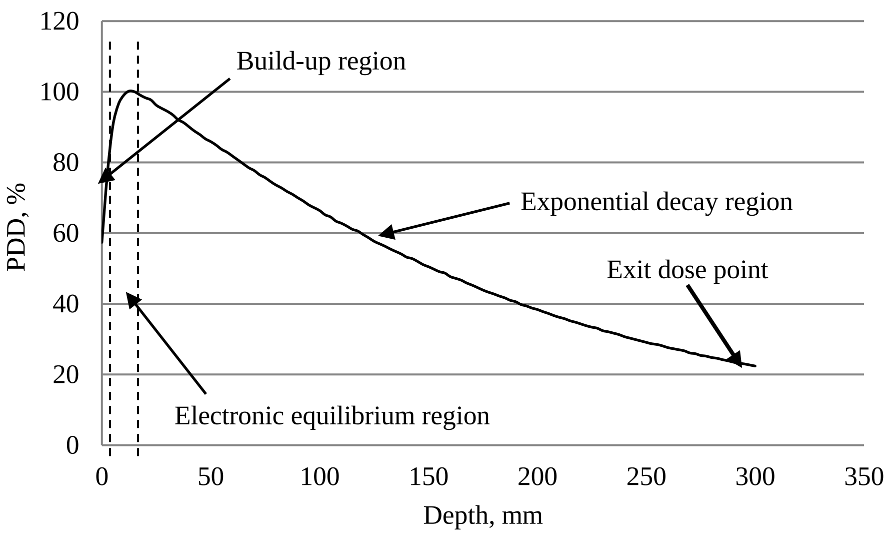

Fig. 1. PDD variation as a function of depth in water phantom.

The PDD curve is formed by three regions: dose build-up region, electronic equilibrium region and exponential decay region with exit dose point in the PDD curve (see Fig. 1). In this study, we are interested in the exit dose point that is at 30 cm for all irradiation field sizes and for both photon beam energies 6 and 18 MV.

2.3. Exit dose study

For studying the exit dose, we have introduced the exit dose rate (EDR) and we have also elaborated an empirical law for prediction of the dose variation at exit dose point. The exit dose rate is determined as a quotient of PDD at exit dose point to side of square field. For high radiation protection quality, we have established an empirical law for EDR calculation with field size.

For evaluating the efficiency of EDR we estimate the difference between the EDR and measurements. We have called this difference by error and it is expressed in percentage according to Eq. 2

$$\mathrm{Error}(\%) = 100 \cdot \frac{(\mathrm{EDR} - \mathrm{Measurement})}{\mathrm{Measurement}}. \qquad (2)$$

3. Results and discussion

This study is based on experimental data measured in radiotherapy department of Al Kawtar clinic center; photon beams are produced by linear accelerator Varian Clinac 2100.

3.1. PDD inside dose build-up region

The PDDs are measured as a function of field size. Fig. 2 shows the PDD variation inside irradiation field size with depth in water phantom for photon beam energy of 6 MV.

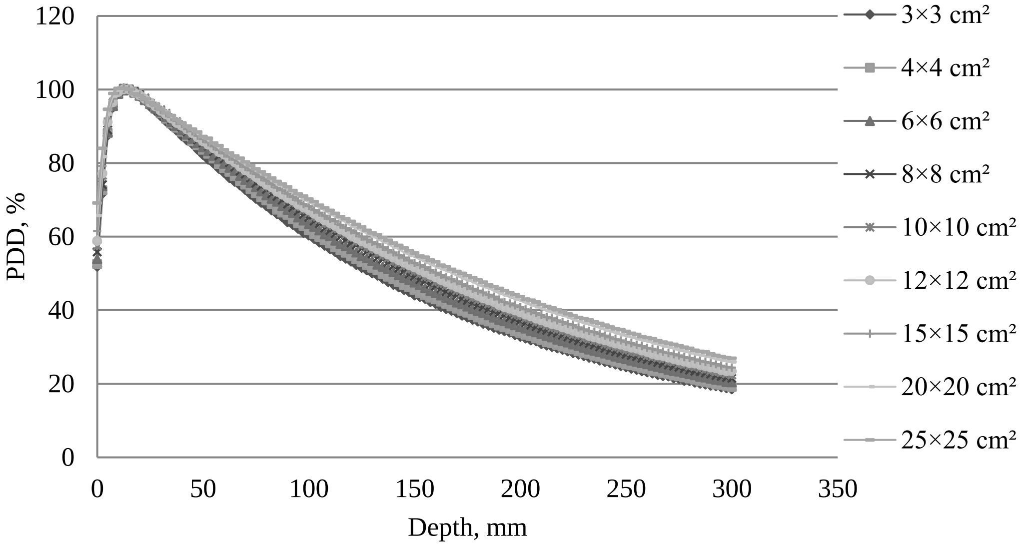

Fig. 2. PDD of 6 MV photon beam energy as a function of depth for different field sizes.

The exit dose of 6 MV photon beam energy increased with field size (see Fig. 2). At the exit dose point (just outside of water phantom), the delivered dose increased with field size. For high radioprotection quality inside the radiotherapy department, this dose should be taken to protect patient and staff. This delivered dose is the highest dose at the exit dose point and it is the maximum dose for the surrounding volume of water phantom for an irradiation field size.

Fig. 3 shows the exit PDDs variation with depth for 18 MV photon beam energy.

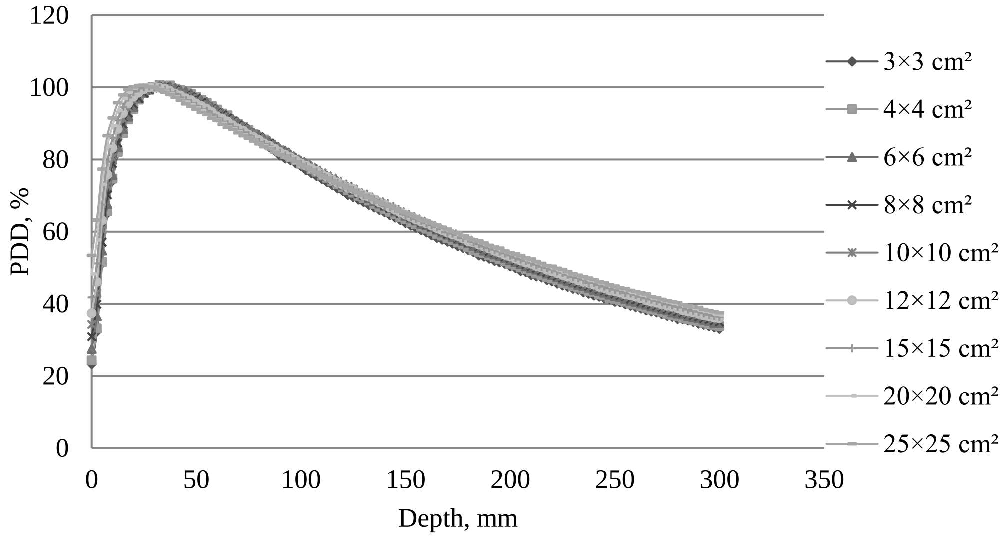

Fig. 3. PDD of 18 MV photon beam energy as a function of depth for different field sizes.

In Fig. 3, we observe the same behavior as in Fig. 2 and the difference between them is that the delivered dose is higher for 18 MV than the delivered dose for 6 MV. Fig. 4 gives the exit dose variation as a function of field size for both photon beam energies 6 and 18 MV.

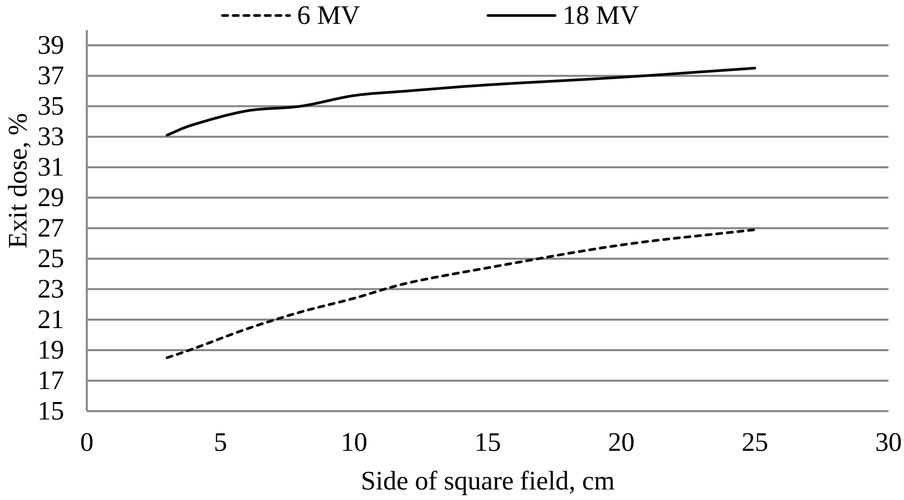

Fig. 4. Exit dose variation as a function of side of square field.

It can be seen from Fig. 4 that exit dose for 18 MV is higher than the exit dose for 6 MV. The exit dose varies linearly with field size for both photon beam energies. The slope of the variation line for 18 MV is lower than the slope of the variation line for 6 MV. The question could be put is how the exit dose varies with field size for both photon beam energies. For this reason, the exit dose rate is introduced.

3.2. Exit dose rate

Fig. 5 shows the exit dose rate variation as a function of irradiation field size for both photon beam energies 6 and 18 MV.

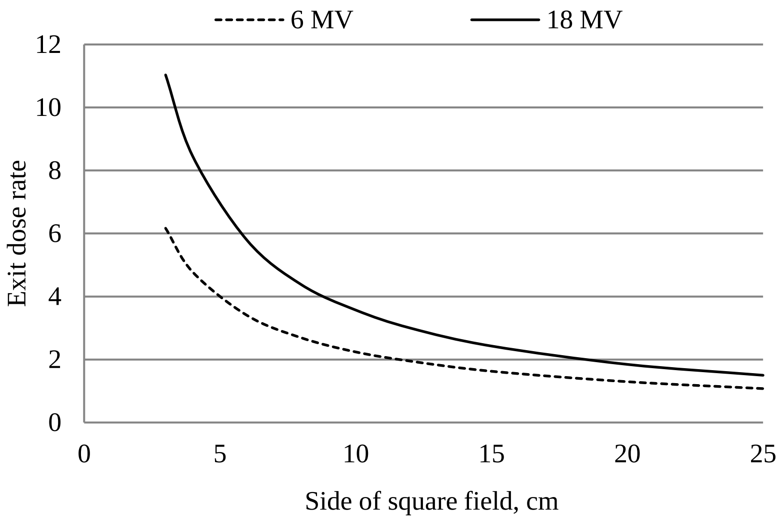

Fig. 5. Exit dose rate variation as a function of side of square field.

It can be seen from Fig. 5 that the exit dose rate decreased with field size for both photon beam energies 6 and 18 MV. The exit dose rate of photon energy of 18 MV is above of the exit dose rate of 6 MV. To predict the exit dose rate for radioprotection quality inside the radiotherapy treatment, the empirical law is given in the following equation:

$$\mathrm{EDR} = \left(1.3 \cdot E + 7.5\right) A^{-(0.009 \cdot E + 0.78)}, \qquad (3)$$

where E – photon beam energy (MV); A – side of square field of irradiation (cm).

Fig. 6 shows the exit dose rate variation determined by this empirical law and compared to measurements for both photon beam energies 6 and 18 MV.

The introduced empirical law reproduces the exit dose rate in dependence on field size with an error under 3 % for both photon beam energies 6 and 6 MV (see Fig. 6). The EDR gives a basic law for reinforcing the radioprotection quality inside the radiotherapy treatment room and this law is reliable by 97 % as shown in Fig. 6.

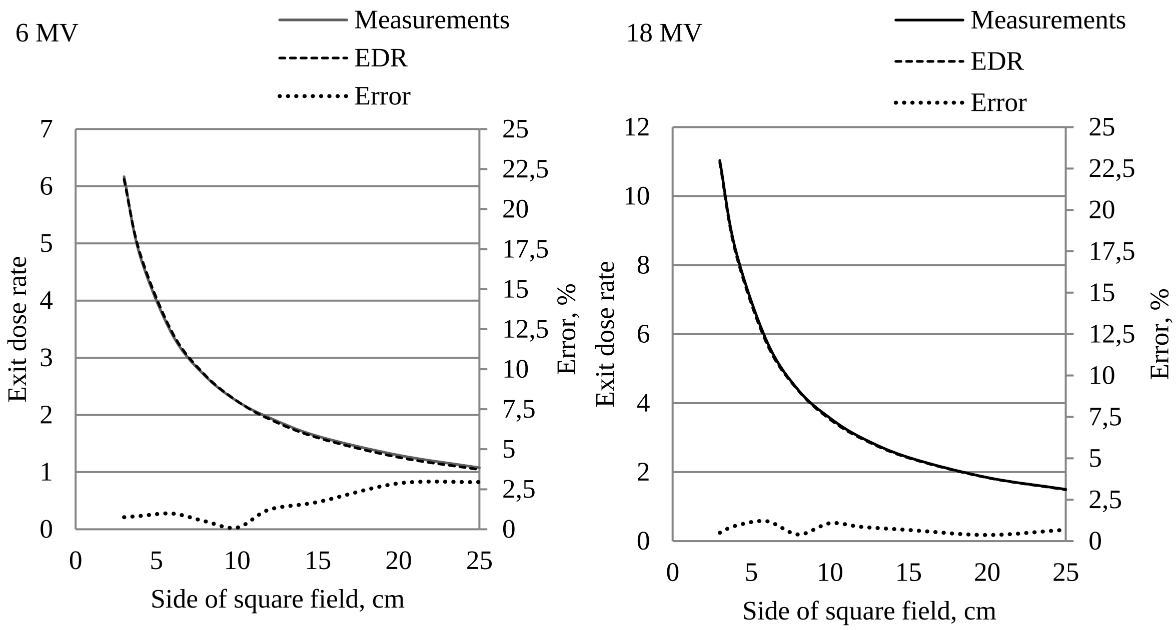

Fig. 6. Empirical law and the associated error as a function of side of square field.

4. Conclusion

This work is an experimental study of exit dose variation with photon beam energy and with irradiation field size. We have evaluated the delivered dose at exit point on PDD curves for both phantom beam energies 6 and 18 MV. The predict-tion of delivered dose outside patient is very important to protect the patient while radiotherapy treatment and also the radiotherapy staff. To reinforce the radioprotection inside radiotherapy treatment room, an empirical law is introduced for evaluating the maximum dose outside water phantom. This empirical law reproduces the measurements with an error under 3 %, so it is the most reliable and can be a basic law that should be used theoretically to know the delivered dose variation with field size at the exit point of PDDs.

This study could increase the radiotherapy efficiency and to reinforce the radioprotection quality in radiotherapy department for photon beam while patient be treated by radiation. For more accuracy of this empirical law, many Monte Carlo studies will do on photon beam energies of 6 and 18 MV [16]. Previously, we have studied the photon beam quality based on the PDD fragmentation [17].

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М. Беншейх[1,]*, А. Магхнудж[1], Д. Таджмуаті[1], А. Діді[1], А. Лямрабет[1], Я. Бенхуя[2,3]

[1] Лабораторія LISTA, кафедра фізики, науковий факультет Дхар Ель-Махраз, університет Сіді Мохамед Бен Абделлах, Фес, Марокко
[2] Відділ променевої терапії, клініка Аль-Кавтар, Фес, Марокко
[3] Лабораторія ядерної фізики, факультет наук, університет Мохамед V в Рабаті, Рабат, Марокко

*****Відповідальний автор: bc.mohamed@gmail.com

НОВИЙ ПІДХІД ДЛЯ ОЦІНЮВАННЯ ЯКОСТІ ВИХІДНОЇ ДОЗИ ДЛЯ НАДІЙНОГО ЗАХИСТУ ВІД РАДІАЦІЇ ТА ЕФЕКТИВНОЇ РАДІОТЕРАПІЇ

Для безпеки та захисту від радіації при променевій терапії вихідну дозу оцінюють з урахуванням розміру поля опромінення та енергії фотонного пучка. Метою даного дослідження є формулювання емпіричного закону для прогнозування дози, доставленої на протилежний бік пацієнта під час променевої терапії раку. У цьому дослідженні вихідна доза є дозою на виході з фантома на центральній осі пучка. Відсоткова глибинна доза була виміряна як функція розміру поля опромінення з невизначеністю 2 %, як це рекомендовано протоколами МАГАТЕ для двох енергій фотонного пучка 6 та 18 МВ. Для забезпечення високої якості захисту від радіації у відділі променевої терапії було знайдено емпіричну закономірність, що виконується з достовірністю 97 %. Це основний закон, який слід використовувати для обчислення варіації величини дози залежно від розміру поля опромінення в точці її виходу, що дає змогу оцінити дозу за межами області опромінення при радіотерапії. Медичним фізикам і лікарям рекомендовано використовувати цей закон у променевій терапії раку.

Ключові слова: накопичення дози, променева терапія, фотонний пучок, дозиметрія, якість променевої терапії.

М. Беншейх[1,]*, А. Магхнудж[1], Д. Таджмуати[1], А. Диди[1], А. Лямрабет[1], Я. Бенхуя[2,3]

[1] Лаборатория LISTA, кафедра физики, научный факультет Дхар Ель-Махраз, университет Сиди Мохамед Бен Абделлах, Фес, Марокко
[2] Отдел лучевой терапии, клиника Аль-Кавтар, Фес, Марокко
[3] Лаборатория ядерной физики, факультет наук, университет Мохамед V в Рабате, Рабат, Марокко

*****Ответственный автор: bc.mohamed@gmail.com

НОВЫЙ ПОДХОД ДЛЯ ОЦЕНКИ КАЧЕСТВА ВЫХОДНОЙ ДОЗЫ ДЛЯ НАДЕЖНОЙ ЗАЩИТЫ ОТ РАДИАЦИИ И ЭФФЕКТИВНОЙ РАДИОТЕРАПИИ

Для безопасности и защиты от радиации при лучевой терапии выходную дозу оценивают с учетом размера поля облучения и энергии фотонного пучка. Целью данного исследования является формулирование эмпирического закона для прогнозирования дозы, доставленной на противоположную сторону пациента во время лучевой терапии рака. В этом исследовании выходная доза равна дозе на выходе из фантома на центральной оси пучка. Процентная глубинная доза была измерена как функция размера поля облучения с неопределенностью 2 %, как это рекомендовано протоколами МАГАТЭ для двух энергий фотонного пучка 6 и 18 МВ. Для обеспечения высокого качества защиты от радиации в отделе лучевой терапии была найдена эмпирическая закономерность, которая выполняется с достоверностью 97 %. Это основной закон, который следует использовать для вычисления вариации величины дозы в зависимости от размера поля облучения в точке ее выхода, что позволяет оценить дозу за пределами области облучения при радиотерапии. Медицинским физикам и докторам рекомендовано использовать этот закон в лучевой терапии рака.

Ключевые слова: накопление дозы, лучевая терапия, фотонный пучок, дозиметрия, качество лучевой терапии.

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